# The Main Injector particle production Experiment (MIPP) at Fermilab

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**Abstract.** We describe the physics capabilities and status of the MIPP experiment which is scheduled to enter its physics data taking period during December 2004-July 2005. We show some of the results obtained from the engineering run that concluded in August 2004 and point out the unique features of MIPP that make it an ideal apparatus to study non-perturbative QCD properties.

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## 1. Introduction

The Main Injector Particle Production Experiment (FNAL E-907, MIPP) [1] is situated in the Meson Center beamline at Fermilab. It received its approval [2] in November 2001 and has installed both the experiment and a newly designed secondary beamline in the interim. It received its first beams in March 2004 and concluded its engineering run in August 2004. The physics data taking run of MIPP is scheduled for the running period December 2004-July 2005.

MIPP is designed primarily as an experiment to measure and study in detail the dynamics associated with non-perturbative strong interactions. It has nearly 100% acceptance for charged particles and excellent momentum resolution. Using particle identification techniques that encompass $dE/dX$, time-of-flight [3], Multi-Cell Cerenkov [4] and a Ring Imaging Cerenkov (RICH)detector [5], MIPP is able to identify charged particles at the $3\sigma$ or better level in nearly all of its final state phase space.

As currently envisaged, MIPP will provide events of unparalleled quality and statistics for beam momenta ranging from 5 GeV/c to 90 GeV/c for 6 beam species ($\pi^{\pm}, K^{\pm}$ and $p^{\pm}$.)

## 2. Physics Motivation

The primary physics motivation behind MIPP is to restart the study of non-perturbative QCD interactions, which constitute over 99% of the strong interaction cross section. The available data are of poor quality and old and are not in easily accessible form. The Time Projection Chamber (TPC) [6] that is at the heart of the MIPP experiment represents the electronic equivalent of the bubble chamber with vastly superior data acquisition rates. It also digitizes the charged tracks in three dimensions, obviating the need for track matching across stereo views. Coupled with the particle identification capability of MIPP, the data from MIPP would add significantly to our knowledge base of non-perturbative QCD.

One of the primary goals of the present run of MIPP is to verify a general scaling law of inclusive particle production that states that the ratio of a semi-inclusive cross section to an

**Table 1.** MIPP running scenario

| Program | Targets | Number of events ($10^6$) |
|---|---|---|
| Atm. Neutrinos | $N_2$ | 3.00 |
| NUMI | thin C, NUMI Target | 10.01 |
| proton-Nucleus | Be, Cu, Pb | 17.20 |
| QCD Scaling | $H_2, D_2$ | 24.40 |
| proton radiography | Be, C, Cu, Pb, U | 20.79 |

inclusive cross section involving the same particles is a function only of the missing mass squared ($M^2$) of the system and not of the other two Mandelstam variables $s$ and $t$, the center of mass energy squared and the momentum transfer squared, respectively.

Stated mathematically, the ratio

$$\frac{f_{subset}(a + b \rightarrow c + X)}{f(a + b \rightarrow c + X)} \equiv \frac{f_{subset}(M^2, s, t)}{f(M^2, s, t)} = \beta_{subset}(M^2) \tag{1}$$

*i.e.*, a ratio of two functions of three variables is only a function of one of them. This scaling relation has been shown to hold very well in a limited number of reactions [7]. MIPP will test this scaling for 36 reactions as a function of both $s$ and $t$ with great accuracy.

In addition to this, MIPP will acquire high quality data in liquid hydrogen with excellent particle ID and statistics over a range of beam momenta, which should make possible a systematic study of exclusive reactions that is essential for testing any future theory of non-perturbative QCD. We can also make forays into searches for exotic resonances such as glueballs and pentaquarks. The existence of beams of differing flavor and energies will be a great advantage in sorting out the flavor content of any new states seen. The other physics clients for MIPP data are nuclear and heavy ion physics groups who are interested in data from several nuclear targets. An important service measurement MIPP hopes to perform is the measurement of particle production off the NUMI target in order to minimize the systematics in the near/far detector ratio in the MINOS [8] experiment. NUMI target measurements by MIPP will also benefit the Minerva [9] and the Nova [10] experiments planned in the NUMI beamline in the future. MIPP will also make measurements with proton beams off various nuclei for the needs of proton radiography [2].

Another measurement MIPP hopes to make is that of pion and proton cross-sections off liquid nitrogen targets for the better prediction of atmospheric neutrino fluxes. MIPP is approved for $1.3 \times 10^6$ spill seconds of beam to be partitioned according to the running modes shown in table 1.

## 3. Experimental Setup

We designed a secondary beam [11] specific to our needs. The 120 GeV/c primary protons extracted by slow resonant extraction from the Fermilab Main Injector are transported down the Meson Center line at Fermilab. They impinge on a 20cm long copper target producing secondary beam particles. This target is imaged on to an adjustable momentum selection collimator which controls the momentum spread of the beam. This collimator is re-imaged on to our interaction target placed next to the TPC. The beam is tracked using three beam chambers and identified using two differential Cerenkovs [12] filled with gas, the composition and the pressure of which can be varied within limits depending onthe beam momentum and charge.

The study of non-perturbative QCD is of fundamental importance to our field. However, we place too little priority on re-embarking on this quest, largely because of the lack of a fundamental theory. MIPP hopes to change this state of affairs by obtaining high quality data with large statistics, which it will publish as DST's on DVD's for public use. However, it was important that the cost of the detector be low in order for the experiment to be approved and this was achieved by refurbishing several existing pieces of apparatus. Figure 1 shows the layout of the apparatus. The TPC sits in a wide aperture magnet (the Jolly Green Giant) which has a peak field of 0.7 Tesla. Downstream of the TPC are a 96 mirror multi-cell Cerenkov detector filled with $C_4F_{10}$ gas, and a time of flight system. This is followed by a large aperture magnet (Rosie) which runs in opposite polarity (at -0.6 Tesla)to the Jolly Green Giant to bend the particles back into the Ring Imaging Cerenkov counter. The RICH has $CO_2$ as the radiator and an array of phototubes of 32 rows and 89 columns [13].

Downstream of the RICH we have an electromagnetic calorimeter [14] and a hadron calorimeter [15] to measure forward going photons and neutrons. The electromagnetic calorimeter will also serve as a device to measure the electron content of our beam at lower energies, which will be useful for measuring cross sections.
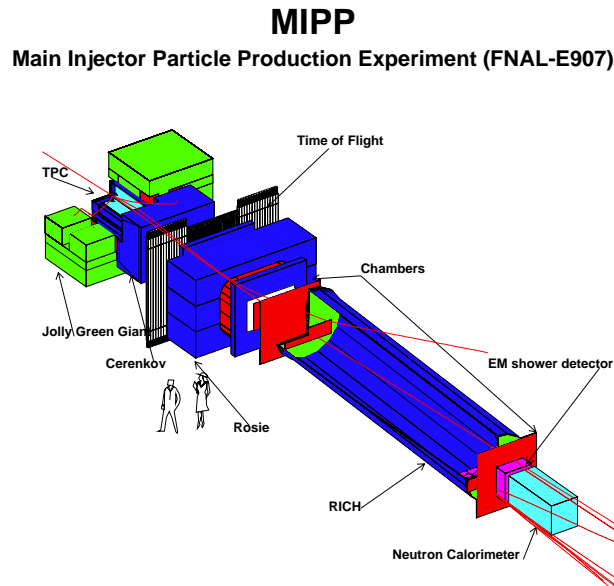
## MIPP
### Main Injector Particle Production Experiment (FNAL-E907)



**Figure 1.** The experimental setup. The picture is a rendition in Geant3, which is used to simulate the detector

MIPP uses $dE/dx$ in the TPC to separate pions, kaons and protons for momenta less than $\approx 1$ $GeV/c$, the time of flight array of counters to do the particle id for momenta less than 2 GeV/c, the multi-cell Cerenkov detector [4] contributes to particle id in the momentum range 2.5 GeV/c-7.5 GeV/c and the RICH [5] for momenta higher than this. By combining information from all counters, we get the expected particle id separation for $K/p$ and $\pi/K$ as shown in Figure 2. It can be seen that excellent separation at the $3\sigma$ or higher level exists for both $K/p$ and $\pi/p$ over almost all of phase space. Tracking of the beam particles and secondary beam particles is accomplished by a set of drift chambers [16] and proportional chambers [17] each of which have 4 stereo layers.
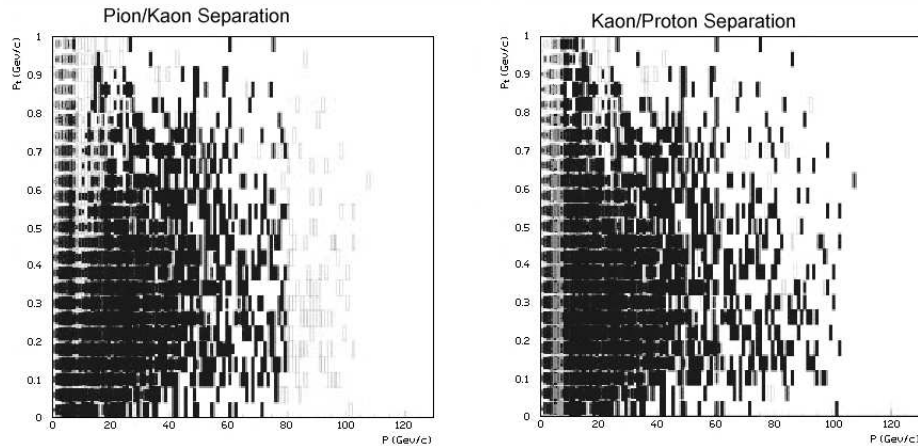
**Figure 2.** Particle ID plots for pion/kaon separation and for kaon/proton separation as a function of the longitudinal and transverse momentum of the outgoing final state particle. Black indicates separation at the $3\sigma$ level or better and grey indicates separation at the $1 - 3\sigma$ level.

## 4. Engineering run results

Figure 3 shows the pictures of reconstructed tracks in the TPC obtained during the engineering run. The tracks are digitized and fitted as helices in three dimensions. Extrapolating three dimensional tracks to the other chambers makes the pattern recognition particularly easy.

Figure 4 shows events with rings in the RICH counter. Some are due to single beam tracks and others are due to tracks from interactions. Figure 5 shows the histogram of ring radii for a +40GeV secondary beam. There is clean separation between pions and kaons and protons and their relative abundances [18] match expectations. Applying the particle ID trigger from the beam Cerenkovs enables us to separate the three particle species cleanly. The kaons which form 4% of the beam are cleanly picked out by the beam Cerenkov with very simple selection criteria. These can be made much more stringent with offline cuts to produce a very clean kaon beam.

## 5. Plans to upgrade MIPP

At present the data taking rate in MIPP is limited by the 60HZ rate imposed on us by the TPC electronics. These can be made considerably faster (by at least a factor of 20) [19] with more modern electronics. Upgrading the TPC electronics this way accompanied by modest upgrades to the rest of the system is expected to cost $\approx \$0.3M$. If approved in 2005, such an upgrade can be implemented in time to continue the MIPP run in 2006. This will enable MIPP to expand its present scope to include pentaquark searches, searches for missing baryon resonances as well as partial wave analyses using low energy beams.

[1] The main MIPP web page is at http://ppd.fnal.gov/experiments/e907/. The MIPP collaboration list may be found at http://ppd.fnal.gov/experiments/e907/Contacts/
[2] The MIPP proposal and Addendum to the proposal may be found at http://ppd.fnal.gov/experiments/e907/Proposal/E907_Proposal.html
[3] The Time of Flight detector was fabricated by MIPP and consists of an array of 10cm×10cm scintillators and 5cm×5cm scintillators. See http://ppd.fnal.gov/experiments/e907/TOF/TOF.html for a detailed description of the detector.
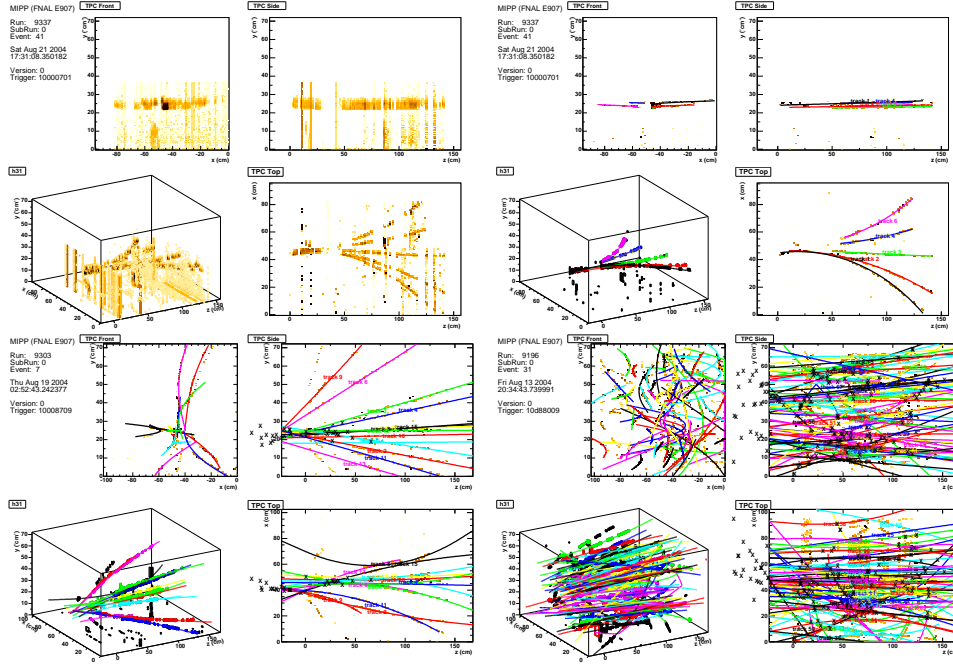
**Figure 3.** Pictures of TPC events. The first set of four pictures on the top left hand side show the raw digitizations of an event in 4 views and the set of four pictures on the right hand side show the tracks pattern recognized on the same event. Tracks in different views have the same color. The last picture is that of an upstream interaction. The offline algorithm has found all the tracks
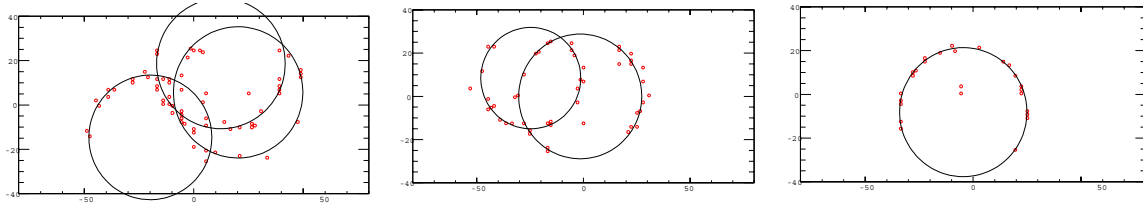


**Figure 4.** Examples of events with rings in the RICH counter for a 40 GeV/c beam.

[4] The multi-cell Cerenkov detector was initially built for Brookhaven Experiment E766 and later in Fermilab experiment E690 and then used in several other Brookhaven experiments. In MIPP, we fill the detector with the gas $C_4F_{10}$ which has the appropriate refractive index at atmospheric pressure.

[5] The details of the SELEX RICH construction and performance may be found at J. Engelfried *et al.* *Nucl. Instr. and Meth.* **A43**,53(1999). We have replaced the front end electronics, and done extensive work on the safety systems. MIPP uses $CO_2$ gas as the radiator for the RICH.

[6] The TPC was built by the BEVALAC group at Berkeley in the 1990's and used effectively at several Brookhaven experiments (e.g. E910) and then donated to Fermilab by LBNL for use in MIPP. See, G. Rai *et al., IEEE Trans.Nucl.Sci.***37**,56(1990);LBL-28141.

[7] R.Raja, *Phys. Rev. D* **18**, 204 (1978). R.Raja, *Phys. Rev. D* **16**, 142 (1977). R.Raja, Y.Fisyak in Proceedings of the DPF92 meeting, Fermilab.

[8] MINOS proposal may be found at "P-875: A long baseline neutrino oscillation experiment at Fermilab", E. Ables*et al.*; FERMILAB-PROPOSAL-P875,(1995). See also their website at http://www-numi.fnal.gov/

[9] The Minerva website is at http://www.pas.rochester.edu~ksmcf/minerva/

[10] The Nova experiment is currently still a proposal and the website is at http://www-nova.fnal.gov/
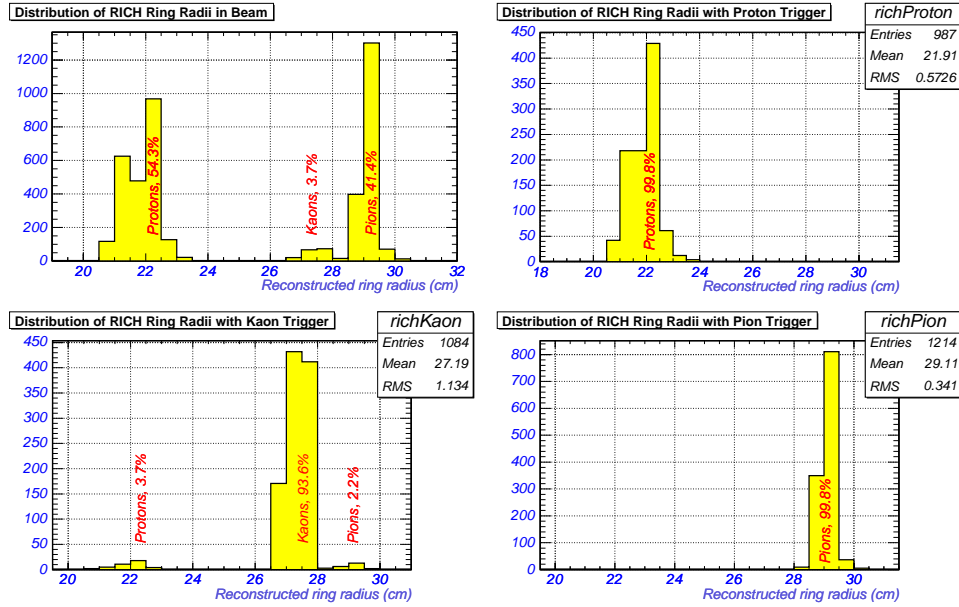
**Figure 5.** An example of a 40 GeV/c primary beam trigger. The RICH identifies protons, kaons and pions by the ring radii. The beam Cerenkov detectors can be used to do the same. When the beam Cerenkov id is used, one gets a very clean separation of pions, kaons and protons in the RICH

[11] "Beamline design for particle production Experiment, E907 at FNAL", C.Johnstone *et al.*, Proceedings of the PAC03 conference.

[12] For more details on the beam Cerenkov system, see
http://ppd.fnal.gov/experiments/e907/Beam/BeamCerenkov/BeamCerenkov.html

[13] During the engineering run, we lost 20% of the phototubes in the RICH due to a fire in one of the bases. This does not impact adversely on our pattern recognition, since the Cerenkov angle is large and there is plenty of light over most of our momentum range

[14] The electromagnetic calorimeter was fabricated by MIPP and uses lead as the radiator and an array of proportional tubes with 2.54 cm wire spacing as the readout. It has  10 radiation lengths and has 10 longitudinal segments.

[15] The hadron calorimeter is recycled from the HyperCP collaboration and uses scintillator fibers embedded in iron as readout. It has 9.7 interaction lengths and has four longitudinal segmentations each of which is segmented in two transversely.

[16] We have reused beam and drift chambers from the E690 collaboration. D.C.Christian *et al. Nucl. Instr. and Meth.* **A345,62** (1994).

[17] The large proportional chambers straddling the RICH find their use again after having been used by numerous previous experiments. M. De Palma *et al. Nucl. Instr. and Meth.* **216** (1983) 393-397.

[18] A. Malensek, Fermilab Technical Memo FN-341, 1981. (unpublished).

[19] The TPC DAQ upgrade scheme may be found at
http://ppd.fnal.gov/experiments/e907/notes/MIPPnotes/public/ps/MIPP0042/MIPP0042.ps.gz